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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. 1.53(b))

Attorney Docket No.	5000 89A
First Inventor	Hua-Shuang Kong et al.
Title	Susceptor Designs for Silicon Carbide Thin Films
Express Mail Label No.	EL473031092US

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1 ☒ Fee Transmittal Form (e.g., PTO/SB/17)
(Submit an original and a duplicate for fee processing)

2 ☐ Applicant claims small entity status. See 37 CFR 1.27.

3 ☒ Specification [*Total Pages* 23]
(preferred arrangement set forth below)
- Descriptive title of the Invention
- Cross References to Related Applications
- Statement Regarding Fed sponsored R & D
- Reference to sequence listing, a table, or a computer program listing appendix
- Background of the Invention
- Brief Summary of the Invention
- Brief Description of the Drawings *(if filed)*
- Detailed Description
- Claim(s)
- Abstract of the Disclosure

4. ☒ Drawing(s) (*35 U.S.C.113*) [*Total Sheets* 6]

5. Oath or Declaration [*Total Pages* 3]
a. ☐ Newly executed (original or copy)
b. ☒ Copy from a prior application (37 CFR 1.63 (d))
(for a continuation/divisional with Box 18 completed)
i ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b)

6. ☐ Application Data Sheet. See 37 CFR 1.76

7. ☐ CD-ROM or CD-R in duplicate, large table or Computer Program *(Appendix)*

8. Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)
a. ☐ Computer Readable Form (CRF)
b. Specification Sequence Listing on:
i. ☐ CD-ROM or CD-R (2 copies); or
ii. ☐ paper
c. ☐ Statements verifying identity of above copies

JC515 U.S. PTO 09/715576 11/17/00

ACCOMPANYING APPLICATIONS PARTS

9. ☐ Assignment Papers (cover sheet & document(s))
10. ☐ 37 C.F.R.§3.73(b) Statement *(when there is an assignee)* ☐ Power of Attorney
11. ☐ English Translation Document *(if applicable)*
12. ☒ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
13. ☒ Preliminary Amendment
14. ☒ Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
15. ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. ☐ Request and Certification under 35 U.S.C. 122 (b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent.
17. ☐ Other:

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:*

☒ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No: 08 / 823 365

Prior application information: Examiner E. Fieler Group / Art Unit: 1763

For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

17. CORRESPONDENCE ADDRESS

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Signature		*Date*	November 17, 2000

PTO/SB/17 (11-00)
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FEE TRANSMITTAL for FY 2001

Patent fees are subject to annual revision

Complete if Known	
Application Number	
Filing Date	Concurrently Herewith
First Named Inventor	Hua-Shuang Kong et al.
Examiner Name	
Group / Art Unit	
Attorney Docket No.	5000.89A

TOTAL AMOUNT OF PAYMENT ($) 836

METHOD OF PAYMENT (check one)

1. ☒ The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:

Deposit Account Number: 50-0332

Deposit Account Name: Philip Summa, P.A.

☒ Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17

☐ Applicant claims small entity status. See 37 CFR 1.27

2. ☒ Payment Enclosed:

☒ Check ☐ Credit card ☐ Money Order ☐ Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	710	201	355	Utility filing fee	710
106	320	206	160	Design filing fee	
107	490	207	245	Plant filing fee	
108	710	208	355	Reissue filing fee	
114	150	214	75	Provisional filling fee	

SUBTOTAL (1) ($) 710

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims	27	-20** =	7	X	18	=	126
Independent Claims	3	-3** =	0	X	40	=	0
Multiple Dependent				X		=	0

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	80	202	40	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim, if not paid
109	80	209	40	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 126

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet.	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	390	216	195	Extension for reply within second month	
117	890	217	445	Extension for reply within third month	
118	1,390	218	695	Extension for reply within fourth month	
128	1,890	228	945	Extension for reply within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive – unavoidable	
141	1,240	241	620	Petition to revive – unintentional	
142	1,240	242	620	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	600	244	300	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	130	123	130	Petitions related to provisional applications	
126	180	126	180	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	710	246	355	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	710	249	355	For each additional invention to be examined (37 CFR § 1.129(b))	
179	710	279	355	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify)

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($) 0

SUBMITTED BY

Complete *(if applicable)*

Name (Print/Type)	Stanley B Baker	*Registration No Attorney/Agent)*	35,058	*Telephone*	704-945-6707
Signature	[signature]			*Date*	Novem ber 17, 2000

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Attorney Docket No. 5000.89A **PATENT**

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: Hua-Shuang Kong et al.
Serial No.:
Filed: Concurrently Herewith
For: SUSCEPTOR DESIGNS FOR SILICON CARBIDE
THIN FILMS

November 17, 2000

Assistant Commissioner for Patents
Washington, DC 20231

PRELIMINARY AMENDMENT

Sir:

After the title, please insert

-- Cross-Reference to Related Application

This application is a divisional of copending U.S. application Serial No. 08/823,365, filed March 24, 1997. --.

In the Claims:

Please cancel Claims 8, 9, 11-20, and 33-41, without prejudice before calculating the filing fee.

Respectfully submitted,

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Reg. No. 35,058

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Express Mail Label Number EL473031092US
Date of Deposit: November 17, 2000

I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to Assistant Commissioner for Patents, Box: Patent Application, Washington, DC 20231.

Andie Crumpler

SUSCEPTOR DESIGNS FOR SILICON CARBIDE THIN FILMS

Field of the Invention

The present invention relates to semiconductor manufacturing processes, and in particular relates to an improved susceptor design for epitaxial growth on silicon carbide substrates.

Background of the Invention

The present invention relates to the production of epitaxial layers of semiconductor materials on silicon carbide substrates. Silicon carbide offers a number of advantageous physical and electronic characteristics for semiconductor performance and devices. These include a wide bandgap, high thermal conductivity, high saturated electron drift velocity, high electron mobility, superior mechanical strength, and radiation hardness.

As is the case with other semiconductor materials such as silicon, one of the basic steps in the manufacture of a number of silicon-carbide based devices includes the growth of thin single crystal layers of semiconductor material on silicon carbide substrates. The technique is referred to as "epitaxy," a term that describes crystal growth by chemical reaction used to form, on the surface of another crystal, thin layers of semiconductor materials with defined lattice structures. In many cases, the lattice structure of the epitaxial layers (or "epilayers") are either identical, similar, or otherwise related to the lattice structure of the substrate. Thus, epitaxial growth of either silicon carbide epitaxial layers on silicon carbide substrates or of other semiconductor materials on silicon carbide substrates, is a fundamental technique for manufacturing devices based on silicon carbide.

Silicon carbide is, however, a difficult material to work with because it can crystallize in over 150 polytypes, some of which are separated from one another by very small thermodynamic differences. Furthermore, because of silicon carbide's high melting point (over 2700°C), many processes for working silicon carbide, including epitaxial film deposition, often need to be carried out at much higher temperature than analogous reactions in other semiconductor materials.

Some basic reviews of semiconductor manufacturing technology can be found for example in Sze, <u>Physics of Semiconductor Devices</u>, 2d Ed. (1981), Section 2.2, pages 64-73; or in Dorf, <u>The Electrical Engineering Handbook</u>, CRC Press, (1993) at Chapter 21 "Semiconductor Manufacturing," pages 475-489; and particularly in Sherman, <u>Chemical Vapor Deposition for Microelectronics: Principles, Technologies and Applications</u>, (1987), ISBN 0-8155-1136-1. The techniques and apparatus discussed herein can be categorized as chemical vapor deposition (CVD) or vapor phase epitaxy (VPE) in which reactant gases are exposed to an energy source (e.g. heat, plasma, light) to stimulate a chemical reaction, the product of which grows on the substrate.

There are several basic techniques for CVD epitaxial growth, the two most common of which are the hot (heated) wall reactor and cold wall reactor processes. A hot wall system is somewhat analogous to a conventional oven in that the substrate, the epitaxial growth precursor materials, and the surrounding container are all raised to the reaction temperature. The technique offers certain advantages and disadvantages.

The second common conventional technique is the use of a "cold wall" reactor. In such systems, the substrate to be used for epitaxial growth is placed on a platform within a container (typically formed of quartz or stainless steel). In many systems, the substrate is disk-shaped and referred to as

a "wafer." The substrate platform is made of a material that will absorb, and thermally respond to, electromagnetic radiations.

As is known to those familiar with such devices and techniques, the susceptor's response to electromagnetic radiation is an inductive process in which alternating frequency electromagnetic radiation applied to the susceptor generates an induced (inductive) current in the susceptor. The susceptor converts some of the energy from this inductive current into heat. In many systems, the electromagnetic radiation is selected in the radio frequency (RF) range because materials such as glass and quartz are transparent to such frequencies and are unaffected by them. Thus, the electromagnetic radiation passes through the container and is absorbed by the susceptor which responds by becoming heated, along with the wafer, to the temperatures required to carry out the epitaxial growth. Because the container walls are unaffected by the electromagnetic energy, they remain "cold" (at least in comparison to the susceptor and the substrate), thus encouraging the chemical reaction to take place on the substrate.

A thorough discussion of the growth of silicon carbide epitaxial layers on silicon carbide substrates is set forth for example in U.S. Patents Nos. 4,912,063 to Davis et al. and 4,912,064 to Kong et al., the contents of both of which are incorporated entirely herein by reference.

The use of a cold wall reactor to carry out epitaxial growth, although satisfactory in many respects, raises other problems. In particular, because a semiconductor wafer rests on a susceptor, the wafer side in contact with the susceptor will become warmer than the remainder of the substrate. This causes a thermal gradient in the axial direction through the wafer. In turn, the difference in thermal expansion within the wafer caused by the axial gradient tends to cause the

peripheral edges (typically the circumference because most wafers are disc-shaped) to curl away from, and lose contact with, the susceptor. As the edges lose contact with the susceptor, their temperature becomes lower than the more central portions of the wafer, thus producing a radial temperature gradient in the substrate wafer in addition to the axial one.

These temperature gradients, and the resulting physical effects, have corresponding negative affects on the characteristics of the substrate and the epitaxial layers upon it. For example, if the edges are placed in extreme tension, they have been observed to crack and fail catastrophically. Even if catastrophic failure is avoided, the epitaxial layers tend to contain defects. At silicon carbide CVD growth temperatures (e.g. 1300°-1800°C), and using larger wafers (i.e. two inches or larger), wafer bending becomes a significant problem. For example, Figure 3 herein plots the values of wafer deflection (H) at various axial temperature gradients as a function of the wafer diameters.

Furthermore, because wafers have a finite thickness, the heat applied by the susceptor tends to generate another temperature gradient along the central axis of the wafer. Such axial gradients can both create and exacerbate the problems listed above.

Yet another temperature gradient typically exists between the rear surface of the substrate wafer and the front surface of the susceptor; i.e. a surface-to-surface gradient. It will thus be understood that both radiant and conductive heat transfer typically take place between susceptors and substrate wafers. Because many susceptors are formed of graphite coated with silicon carbide, the thermodynamic driving force created by the large temperature gradients between the susceptor and the silicon carbide wafers also causes the silicon carbide

coating to undesirably sublime from the susceptor to the wafer.

Additionally, because such sublimation tends to promote pin hole formation in the susceptor coating, it can permit contaminants from the graphite to escape and unintentionally dope the substrates or the epilayers. This in turn ultimately leads to non-uniform doping levels in the semiconductor material, and reduces the lifetime of the susceptor. The problems created by susceptors which undesirably emit dopants is set forth for example in the background portion of U.S. Patent No. 5,119,540 to Kong et al.

Nevertheless, a need still exists for susceptors that can operate at the high temperatures required for silicon carbide processing while minimizing or eliminating these radial, axial and surface to surface temperature gradients, and the associated physical changes and problems.

Object and Summary of the Invention

Therefore, it is an object of the present invention to provide a susceptor for minimizing or eliminating radial, axial and surface-to-surface thermal gradients across a substrate wafer.

The invention meets this object with a susceptor that comprises a first portion that includes a surface for receiving a semiconductor substrate wafer thereon, and a second portion facing the substrate receiving surface and spaced from the substrate receiving surface with the spacing being sufficiently large to permit the flow of gases therebetween for epitaxial growth on a substrate. The spacing remains small enough, however, for the second susceptor portion to heat the exposed face of a substrate to substantially the same temperature as the first susceptor

portion heats the face of the substrate that is in direct contact with the substrate receiving surface.

In another aspect, the invention is a method for minimizing or eliminating thermal gradients in and around a substrate during epitaxial growth by heating a portion of a susceptor that faces, but avoids contact with, a semiconductor substrate, and that is spaced sufficiently far from the substrate to permit the flow of gases between the substrate and the susceptor portion to encourage epitaxial growth on the substrate facing the susceptor portion wherein the susceptor is thermally responsive to the irradiating radiation.

The foregoing and other objects, advantages and features of the invention, and the manner in which the same are accomplished, will be more readily apparent upon consideration of the following detailed description of the invention taken in conjunction with the accompanying drawings, which illustrate preferred and exemplary embodiments, and wherein:

Brief Description of the Drawings

Figure 1 is a cross-sectional view of a platform type chemical vapor deposition (CVD) system;

Figure 2 is a cross-sectional view of a barrel-type CVD system;

Figure 3 is a graph illustrating the relationship between wafer deflection and wafer diameter at various temperature gradients;

Figure 4 is a schematic view of a barrel-type susceptor;

Figure 5 is a schematic view of wafer deflection and temperature gradients;

Figure 6 is a cross-sectional view of one embodiment of a susceptor according to the present invention;

Figure 7 is a partial cross-sectional view of a second embodiment of the susceptor of the present invention;

Figure 8 is a cross-sectional view of a pancake-type susceptor;

Figure 9 is a top plan view of a pancake-type susceptor; and

Figure 10 is a cross-sectional view of a pancake-type susceptor according to the present invention.

Detailed Description of the Preferred Embodiments

The present invention is a susceptor for minimizing or eliminating thermal gradients, including radial, axial, and surface-to-surface gradients, that affect a substrate wafer during epitaxial growth. Substrates according to the present invention are particularly useful for chemical vapor deposition systems as illustrated in Figures 1 and 2. Figure 1 shows a platform or pancake type CVD system broadly designated at **20**. The system comprises a reactor vessel **21** formed of a material, typically a quartz tube or bell jar, that is substantially transparent to the appropriate frequencies of electromagnetic radiation. A gas supply system is in fluid communication with the reaction vessel **21** and in Figure 1 is illustrated as the gas injector **22**.

The system includes a source of electromagnetic radiation that in Figure 1 is illustrated as the induction coils **25**. The operation of such generators and induction coils is generally well known to those of ordinary skill in the art, and will not be discussed further herein in detail. As is also understood in this art, alternative heating techniques can include electric resistance heating, radiant lamp heating, and similar techniques.

The chemical vapor deposition system shown in Figure 1 also includes the platform type susceptor **26** with semiconductor substrates, typically disc-shaped wafers **27**.

thereon. Figure 1 also illustrates the pumping port **30** for evacuating the system as desired.

Figure 2 illustrates a system that is very similar in terms of its basic operation, but that is a barrel-type susceptor, rather than a pancake-type. In Figure 2, the CVD system is broadly designated at **32** and shows a reaction vessel **33** which is surrounded by a water jacket **34** which circulates water against the walls of the reaction vessel **33**. The CVD system **32** also includes a gas inlet **35** and a gas exhaust **36**, a water inlet **37** and the water outlet **40**, and a lifting and rotation assembly **41** for the susceptor.

The susceptor itself is broadly designated at **42** and is in the general shape of a cylinder, although with a shallow slope that gives it somewhat frustoconical shape. The cylinder is formed of a plurality of adjacent straight sidewall sections **43** that define the cylinder. A plurality of wafer pockets **44** are positioned on the sidewalls **43** and hold the semiconductor substrates thereon. The slight incline of the susceptor walls help keep the wafers in the pockets **44**, and improve the uniformity of the resulting epilayers by encouraging more favorable gas flow. Figure 2 also illustrates the power supply **45** for the induction coil broadly designated at **46**.

Figure 3 is a graph that helps illustrate the problem addressed by the present invention. In Figure 3, the deflection of a wafer expressed in thousandths of an inch is plotted against the wafer diameter in inches for three different temperature gradients ("Delta T"). As noted in Figure 3, the susceptor surface temperature is 1530°C and the wafer thickness is 12 mils (0.012 inch). As Figure 3 illustrates, wafer deflection represents a minimal problem when the diameter of the substrate wafer is about an inch or less. For larger wafers, particularly those of two, three or

even four inches, the deflection becomes more severe, even at relatively low temperature gradients.

Figure 4 illustrates a barrel type susceptor similar to that used in the illustration of Figure 2. Using the same numbering system as Figure 2, the susceptor is broadly designated at **42**, is made of a plurality of straight sidewalls **43** that together define the generally cylindrical shape. The sidewalls **43** include a plurality of wafer pockets **44** for holding the substrate wafer.

Figure 5 is a schematic illustration of the effects of the temperature gradients plotted in Figure 3, and includes the designation of the axial temperature gradient (ΔT_1) and of the radial gradient (ΔT_2).

Figure 6 illustrates a susceptor according to the present invention that is most appropriately used in the barrel type systems illustrated in Figure 2. In the embodiment illustrated in Figure 6, the susceptor is broadly designated at **50** and is a cylinder formed of a plurality of adjacent straight sidewall sections **51**. Figure 6 illustrates two of the sidewalls in cross-section and one in side elevation. The straight sidewall sections **51**, of which there are most typically four, six, or eight, are formed of a material that is thermally responsive to selected frequencies of electromagnetic radiation. As noted above, the most common electromagnetic radiation is in the radio frequency range, so the susceptor material is generally selected to be thermally responsive to such RF frequencies. In preferred embodiments, the susceptor **50** is formed of graphite coated with silicon carbide.

In a presently preferred embodiment, the electromagnetic radiation is applied in the 8-10 kilocycle range using a solid state power supply that takes advantage of the inherent efficiencies of solid state technology. Those familiar with inductive CVD processes will also recognize that thicker

susceptor walls require lower frequencies to achieve the most efficient penetration.

In the embodiment illustrated in Figure 6, the susceptor **50** includes a plurality of wafer pockets **52** on the inner circumference of the cylinder. Thus, when the susceptor **50** is heated, the facing walls radiantly heat the front of the wafers while the susceptor heats the rear. As Figure 6 illustrates, in this embodiment, the sidewalls **51** preferably define an inverted truncated cone with a relatively shallow slope as compared to a true cylinder. As noted earlier, the shallow slope in the sidewalls **51** makes it somewhat easier to retain the wafers in the pockets **52** during chemical vapor deposition, and also helps provide a proper flow pattern for the CVD gases.

Figure 7 illustrates a next embodiment of the invention in which the susceptor comprises a first cylinder (or "barrel") broadly designated at **54**. The cylinder is defined by a plurality of adjacent straight sidewall sections **55**, and is formed of a material that is thermally responsive to selected frequencies of electromagnetic radiation. The cylinder **54** includes a plurality of wafer pockets **56** on the outer surface of the sidewall sections **55**.

A second cylinder broadly designated at **57** surrounds the first cylinder **54** and defines an annular space **A** between the first and second cylinders. The second cylinder **57** is likewise made of a material that is thermally responsive to the selected frequencies of electromagnetic radiation, and the annular space between the first and second cylinders (**54**, **57**) is sufficiently large to permit the flow of gases therebetween for epitaxial growth on substrates in the wafer pockets **56**, while small enough for the second cylinder **57** to heat the exposed face of substrates to substantially the same temperature as the first cylinder **54** heats the faces of substrates that are in direct contact with the first cylinder.

The first and second cylinders **54**, **57** can be formed of either the same or different materials. If used in a barrel type susceptor system as illustrated in Figure 2, the second cylinder **57** tends to heat the first cylinder **54** to encourage the cylinders to reach substantially the same temperatures. As in other embodiments, each of the cylinders is most preferably formed of graphite coated with silicon carbide.

It will be understood that the use of a silicon carbide coating on such susceptors is a function of the ceramic properties of polycrystalline silicon carbide and is otherwise not related to its semiconductor properties. Thus, susceptors made of stainless steel, graphite, graphite coated with silicon carbide, or silicon carbide, are typically used in the semiconductor industry for CVD processes.

Figures 8, 9 and 10 illustrate another susceptor according to the present invention. Figures 8 and 9 illustrate, in cross-section and top plan view respectively, a pancake or plate-shaped susceptor broadly designated at **60**. The susceptor **60** has a top surface **61** for receiving semiconductor substrate wafers thereon. In this embodiment, the invention further comprises a horizontally disposed second susceptor portion **63** parallel to and above the wafer receiving surface **61** of the first susceptor portion **60**. Both of the susceptor portions **60** and **63** are formed of materials that are thermally responsive to selected frequencies of electromagnetic radiation, and as in the previous embodiments, are preferably formed of the same material to be responsive to the same frequencies of electromagnetic radiation. Most preferably, both susceptor portions **60** and **63** are formed of graphite coated with silicon carbide. As in the previous embodiments, the spacing designated **B** (Figure 10) between the two portions **60**, **63** is sufficiently large to permit the flow of gases therebetween for epitaxial growth on a substrate on the surface **61**, while small enough for the second susceptor

portion 63 to heat the exposed face of a substrate to substantially the same temperature as the first susceptor portion 60 heats the face of substrate that is in direct contact with the substrate receiving surface 61. As illustrated in Figures 8, 9 and 10, the top surface 61 of the first horizontal susceptor portion 60 preferably includes a plurality of wafer pockets 64.

In each of these embodiments, it will be understood that the two susceptor portions can be connected to one another, or separate portions of a single susceptor, or independent pieces as may be desired or necessary under various circumstances. Additionally, the optimum spacing between the substrate portions can be determined by computer modeling or actual practice, and without requiring undue experimentation.

In another aspect, the invention comprises a method for minimizing or eliminating thermal gradients in a substrate during epitaxial growth. In this aspect, the invention comprises irradiating a susceptor, or a susceptor portion, that faces, but avoids contact with, a semiconductor substrate wafer, and that is spaced sufficiently far from the wafer to permit the flow of gases between the substrate and the facing susceptor to thereby encourage epitaxial growth on the substrate facing the susceptor portion. As in the structural embodiments, the susceptor is thermally responsive to the irradiating radiation.

As further set forth with respect to the structural aspects of the invention, the invention also preferably comprises concurrently irradiating a separate susceptor portion upon which the wafer rests so that the exposed face of the substrate is heated to substantially the same temperature as is the face of the substrate that is in direct contact with the other susceptor portion.

The method further comprises the steps of directing source gases that flow between the heated susceptor portions.

If the epitaxial layers are to be formed of silicon carbide, the method preferably comprises directing silicon and carbon containing source gases such as silane, ethylene, and propane.

Where other materials, such as Group III nitrides, are to form the epitaxial layers on the silicon carbide, the step of directing source gases can include directing gases such as trimethyl aluminum, trimethyl gallium, trimethyl indium, and ammonia.

In preferred embodiments, the method also comprises the step of preparing the substrate surface for growth. As set forth in more detail in the references incorporated above, such preparation can comprise steps such as oxidizing the surface followed by a chemical etching step to remove the oxidized portion leaving a prepared surface behind, or alternatively, dry etching the silicon carbide surface to prepare it for further growth. As in most epitaxial growth technique, surface preparation further typically comprises lapping and polishing the substrate surface prior to the oxidation or etching steps.

In the drawings and specifications, there have been disclosed typically preferred embodiments of the invention and, although specific terms have been employed, they have been used in a generic sense and in descriptive sense only, and not for purposes of limitation, the scope of the invention being set forth in the following claims:

THAT WHICH IS CLAIMED:

1. A susceptor for minimizing or eliminating thermal gradients that affect a substrate wafer during epitaxial growth, said susceptor comprising:

a first susceptor portion including a surface for receiving a semiconductor substrate wafer thereon; and

a second susceptor portion facing said substrate-receiving surface and spaced from said substrate-receiving surface, said spacing being sufficiently large to permit the flow of gases therebetween for epitaxial growth on a substrate on said surface, while small enough for said second susceptor portion to heat the exposed face of a substrate to substantially the same temperature as said first susceptor portion heats the face of a substrate that is in direct contact with said substrate-receiving surface.

2. A barrel-type susceptor according to Claim 1.

3. A pancake-type susceptor according to Claim 1.

4. A susceptor according to Claim 1 wherein said first susceptor portion is formed of a material that is thermally responsive to electromagnetic radiation.

5. A susceptor according to Claim 1 wherein said second susceptor portion is formed of a material that is thermally responsive to electromagnetic radiation.

6. A susceptor according to Claim 1 wherein said first and second portions are formed of the same material.

7. A susceptor according to Claim 1 wherein said first and second portions are formed of different materials.

8. A susceptor according to Claim 1 wherein said first susceptor portion is formed of graphite coated with silicon carbide.

9. A susceptor according to Claim 1 wherein said second susceptor portion is formed of graphite coated with silicon carbide.

10. A susceptor according to Claim 1 wherein said substrate receiving surface further comprises a plurality of wafer pockets.

11. A method for minimizing or eliminating thermal gradients that affect a substrate during epitaxial growth, the method comprising:

heating a portion of a susceptor that faces, but avoids contact with, a semiconductor substrate and that is spaced sufficiently far from the substrate to permit the flow of gases between the substrate and the susceptor portion to encourage epitaxial growth on the substrate facing the susceptor portion.

12. A method according to Claim 11 and further comprising concurrently heating a second susceptor portion upon which the wafer rests so that the exposed face of the substrate is heated to substantially the same temperature as is the face of the substrate that is in direct contact with the second susceptor portion.

13. A method according to Claim 11 wherein the heating step comprises irradiating a susceptor that is thermally responsive to certain frequencies of the electromagnetic radiation with electromagnetic radiation within the range of those certain frequencies.

14. A method according to Claim 12 and further comprising the step of directing source gases to flow between the heated susceptor portions.

15. A method according to Claim 12 wherein the source gases are selected from the group consisting of silane, ethylene, propane and mixtures thereof.

16. A method according to Claim 12 wherein the source gases comprise trimethyl gallium and ammonia.

17. A method according to Claim 14 and further comprising the step of preparing the substrate surface for growth.

18. A method according to Claim 17 wherein the substrate comprises silicon carbide, and the surface preparation comprises an oxidation step followed by a chemical etching step to remove the oxidized portion.

19. A method according to Claim 17 wherein the substrate comprises silicon carbide, and the surface preparation comprises dry etching the silicon carbide surface.

20. A method according to Claim 17 wherein the surface preparation comprises lapping and polishing the substrate surface.

21. A chemical vapor deposition system comprising:

a reactor vessel formed of a material substantially transparent to electromagnetic radiation;

a gas supply system in fluid communication with said reactor vessel;

a source of electromagnetic radiation external to said reaction vessel; and

a susceptor within said reaction vessel, and formed of a material that is thermally responsive to electromagnetic radiation, said susceptor comprising,

a first susceptor portion including a surface for receiving a semiconductor substrate wafer thereon; and

a second susceptor portion facing said substrate-receiving surface and spaced from said substrate-receiving surface, said spacing being sufficiently large to permit the flow of gases therebetween for epitaxial growth on a substrate on said surface, while small enough for said second susceptor portion to heat the exposed face of a substrate to substantially the same temperature as said first susceptor portion heats the face of a substrate that is in direct contact with said substrate-receiving surface.

22. A chemical vapor deposition system according to Claim 21 wherein said reaction vessel is made of quartz.

23. A chemical vapor deposition system according to Claim 21 wherein said reaction vessel is made of stainless steel.

24. A chemical vapor deposition system according to Claim 21 wherein said source of electromagnetic radiation comprises an induction coil surrounding said reaction vessel.

25. A chemical vapor deposition system according to Claim 21 wherein said first and second portions are formed of the same material.

26. A chemical vapor deposition system according to Claim 21 wherein said first and second portions are formed of different materials.

27. A chemical vapor deposition system according to Claim 21 wherein said first susceptor portion is formed of graphite coated with silicon carbide.

28. A chemical vapor deposition system according to Claim 21 wherein said second susceptor portion is formed of graphite coated with silicon carbide.

29. A chemical vapor deposition system according to Claim 21 wherein said substrate receiving surface on said first substrate portion comprises a plurality of wafer pockets.

30. A chemical vapor deposition system according to Claim 21 wherein said susceptor comprises:

a cylinder formed of a plurality of adjacent straight sidewall sections that define the cylinder; and

a plurality of wafer pockets on the inner circumference of said cylinder.

31. A chemical vapor deposition system according to Claim 21 wherein said first susceptor portion comprises a first cylinder formed of a plurality of adjacent straight sidewall sections that define the cylinder; and

a plurality of wafer pockets on the outer surface of said sidewall sections; and

said second susceptor portion comprises a second cylinder surrounding said first cylinder and defining an annular space between said first and second cylinders, with the annular space between said first and second cylinders being

sufficiently large to permit the flow of gases therebetween for epitaxial growth on substrates in said wafer pockets, while small enough for said second cylinder to heat the exposed face of substrates to substantially the same temperature as said first cylinder heats the faces of substrates that are in direct contact with said first cylinder.

32. A chemical vapor deposition system according to Claim 21 wherein said first susceptor portion is a horizontal platform having a top surface for receiving semiconductor substrate wafers thereon; and

said second susceptor portion is parallel to and spaced above said wafer-receiving surface of said first susceptor portion, said spacing being sufficiently large to permit the flow of gases therebetween for epitaxial growth on a substrate on said surface, while small enough for said second susceptor portion to heat the exposed face of a substrate to substantially the same temperature as said first susceptor portion heats the face of a substrate that is in direct contact with said substrate-receiving surface.

33. A susceptor for minimizing or eliminating thermal gradients across a substrate wafer, said susceptor comprising:

a cylinder formed of a plurality of adjacent straight sidewall sections that define the cylinder, said cylinder being formed of a material that is thermally responsive to selected frequencies of electromagnetic radiation; and

a plurality of wafer pockets on the inner circumference of said cylinder.

34. A susceptor according to Claim 33 wherein said sidewalls define an inverted truncated cone.

35. A susceptor according to Claim 33 wherein said susceptor material in said cylinder is thermally responsive to radio frequencies.

36. A susceptor according to Claim 33 wherein said cylinder is formed of graphite coated with silicon carbide.

37. A susceptor for minimizing or eliminating thermal gradients across a substrate wafer, said susceptor comprising:

a first cylinder formed of a plurality of adjacent straight sidewall sections that define the cylinder, said cylinder being formed of a material that is thermally responsive to selected frequencies of electromagnetic radiation;

a plurality of wafer pockets on the outer surface of said sidewall sections; and

a second cylinder surrounding said first cylinder and defining an annular space between said first and second cylinders, said second cylinder being made of a material that is thermally responsive to selected frequencies of electromagnetic radiation, with the annular space between said first and second cylinders being sufficiently large to permit the flow of gases therebetween for epitaxial growth on substrates in said wafer pockets, while small enough for said second cylinder to heat the exposed face of substrates to substantially the same temperature as said first cylinder heats the faces of substrates that are in direct contact with said first cylinder.

38. A susceptor according to Claim 37 wherein said first and second cylinders are formed of the same material and are responsive to the same frequencies of electromagnetic radiation.

39. A susceptor according to Claim 37 wherein said first and second cylinders are thermally responsive to radio frequency electromagnetic radiation.

40. A susceptor according to Claim 37 wherein said first cylinder is formed of graphite coated with silicon carbide.

41. A susceptor according to Claim 37 wherein said second cylinder is formed of graphite coated with silicon carbide.

42. A susceptor for minimizing or eliminating thermal gradients across a substrate wafer, said susceptor comprising:

a first susceptor portion formed of a material that is thermally responsive to selected frequencies of electromagnetic radiation, and having a top surface for receiving semiconductor substrate wafers thereon; and

a second susceptor portion parallel to and spaced apart from said wafer-receiving surface of said first susceptor portion and formed of a material that is thermally responsive to selected frequencies of electromagnetic radiation, said spacing being sufficiently large to permit the flow of gases therebetween for epitaxial growth on a substrate on said surface, while small enough for said second susceptor portion to heat the exposed face of a substrate to substantially the same temperature as said first susceptor portion heats the face of a substrate that is in direct contact with said substrate-receiving surface.

43. A susceptor according to Claim 42 wherein said first and second susceptor portions are horizontally oriented.

44. A susceptor according to Claim 42 wherein said first and second susceptor portions are formed of the same material and are responsive to the same frequencies of electromagnetic radiation.

45. A susceptor according to Claim 42 wherein said first and second susceptor portions are thermally responsive to radio frequency electromagnetic radiation.

46. A susceptor according to Claim 42 wherein said first susceptor portion is formed of graphite coated with silicon carbide.

47. A susceptor according to Claim 42 wherein said second susceptor portion is formed of graphite coated with silicon carbide.

48. A susceptor according to Claim 42 wherein said top surface of said first susceptor portion includes a plurality of wafer pockets.

SUSCEPTOR DESIGNS FOR SILICON CARBIDE THIN FILMS

Abstract of the Disclosure

A susceptor is disclosed for minimizing or eliminating thermal gradients that affect a substrate wafer during epitaxial growth. The susceptor comprises a first susceptor portion including a surface for receiving a semiconductor substrate wafer thereon, and a second susceptor portion facing the substrate-receiving surface and spaced from the substrate-receiving surface. The spacing is sufficiently large to permit the flow of gases therebetween for epitaxial growth on a substrate on the surface, while small enough for the second susceptor portion to heat the exposed face of a substrate to substantially the same temperature as the first susceptor portion heats the face of a substrate that is in direct contact with the substrate-receiving surface.

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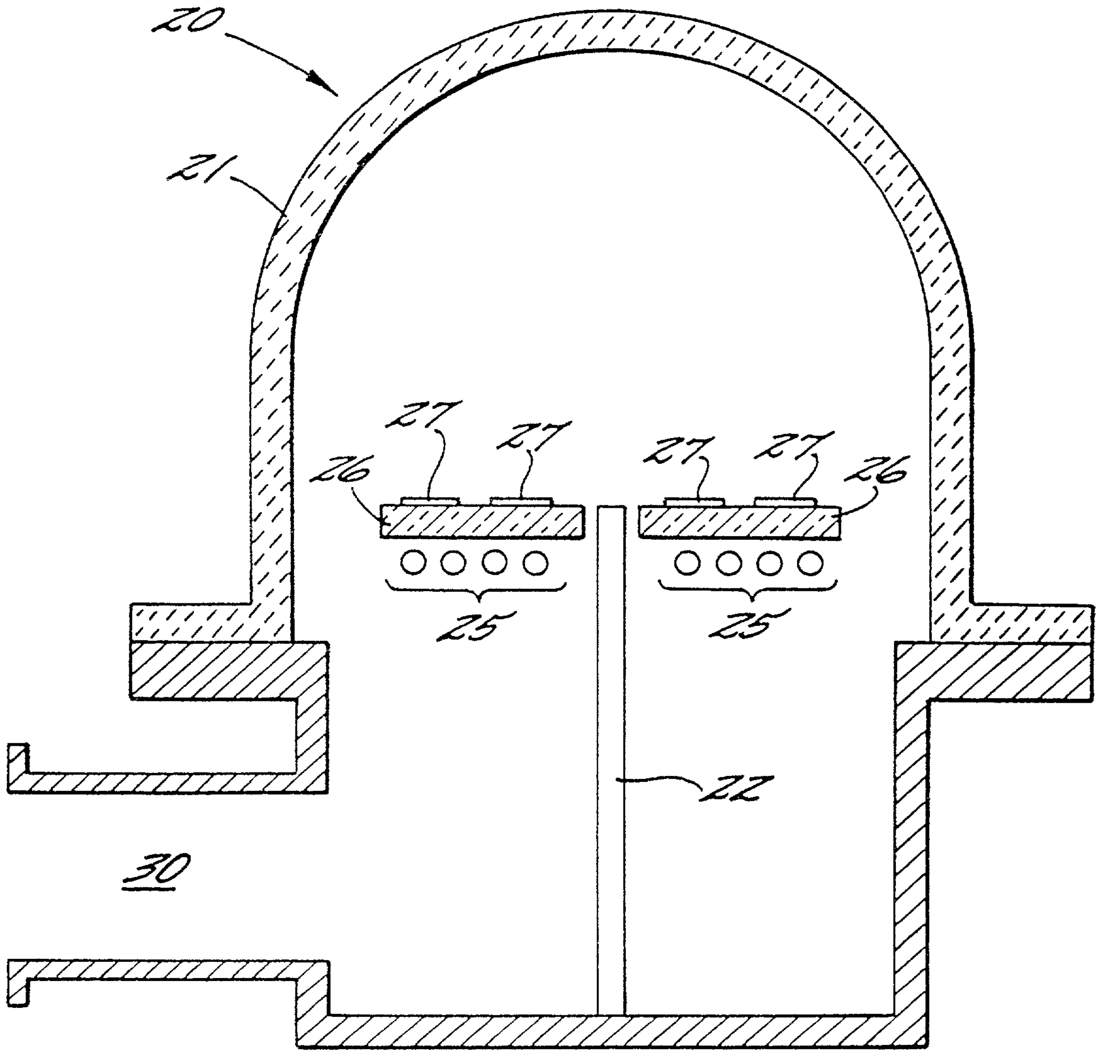
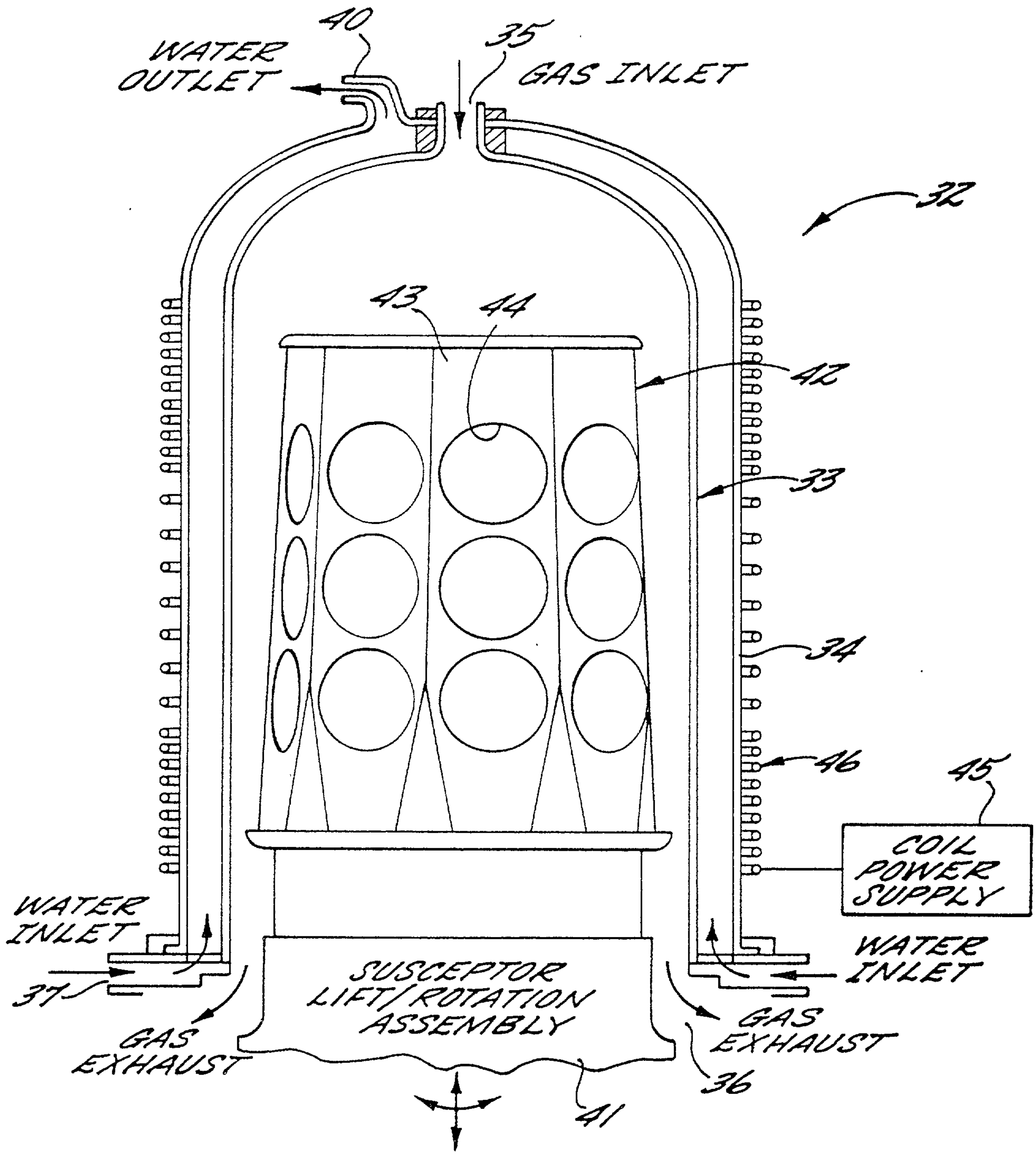


Fig. 1.



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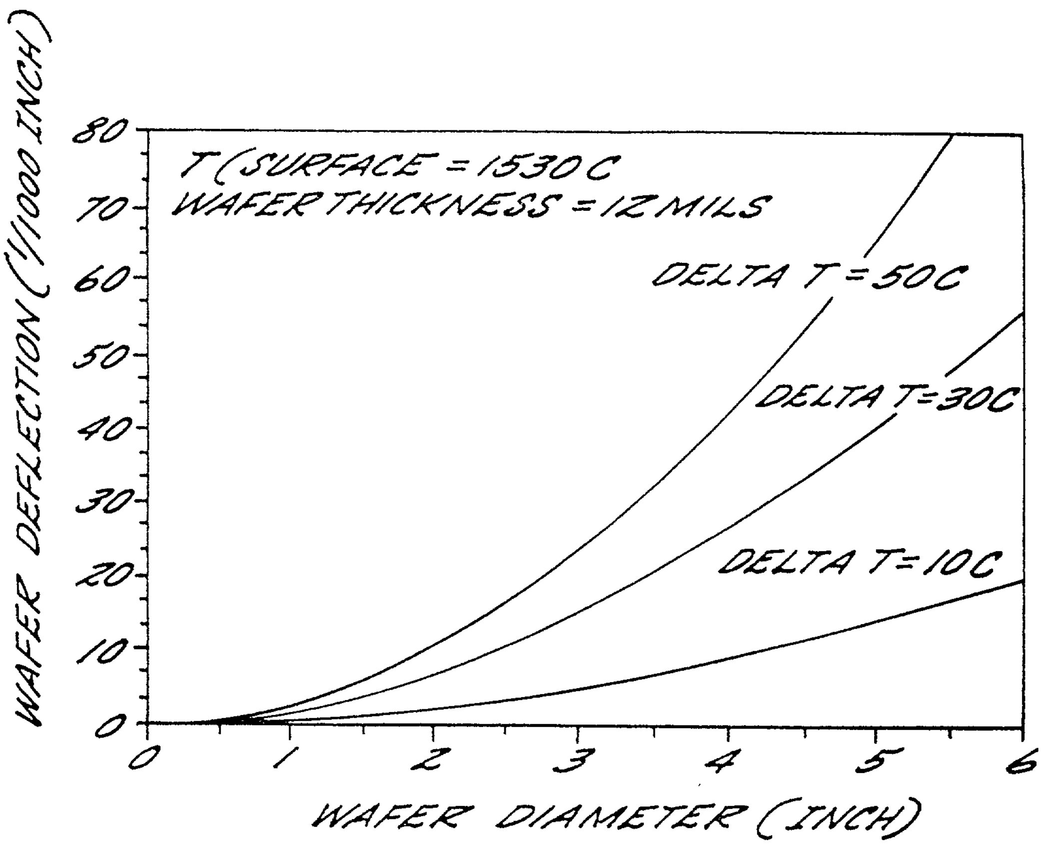
35
WATER OUTLET
GAS INLET
32
43
44
42
33
34
46
45
COIL POWER SUPPLY
WATER INLET
WATER INLET
37
SUSCEPTOR LIFT/ROTATION ASSEMBLY
GAS EXHAUST
GAS EXHAUST
36
41

Fig. 2.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70
60
50
40
30
20
10
0
T (SURFACE = 1530 C
WAFER THICKNESS = 12 MILS
DELTA T = 50C
DELTA T=30C
DELTA T=10C
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2
3
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WAFER DIAMETER (INCH)

Fig. 3.

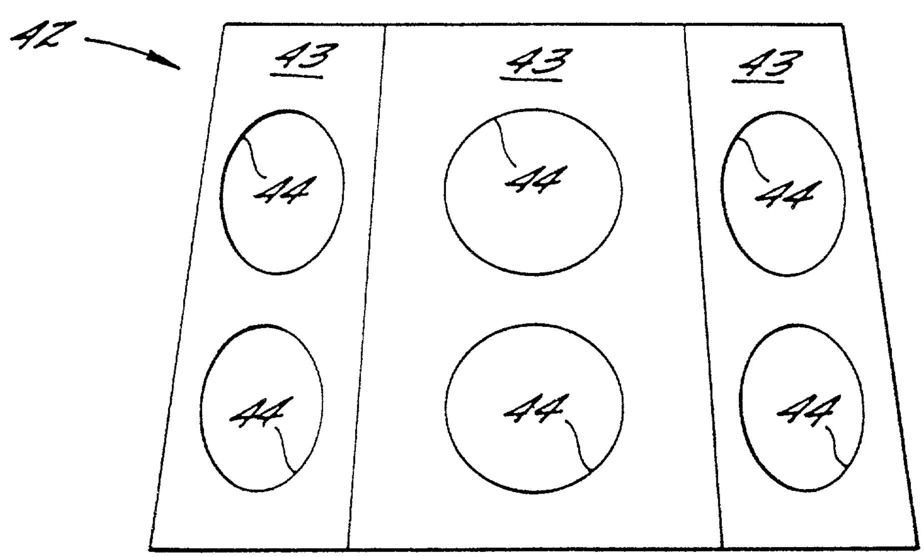
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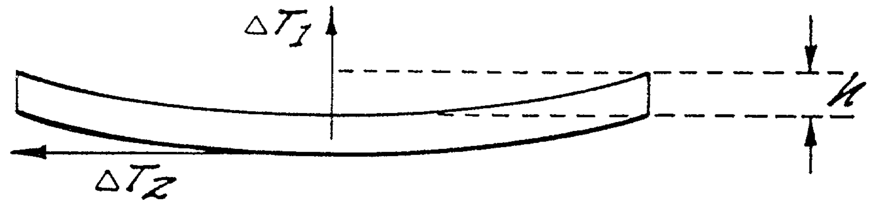
Fig. 4.



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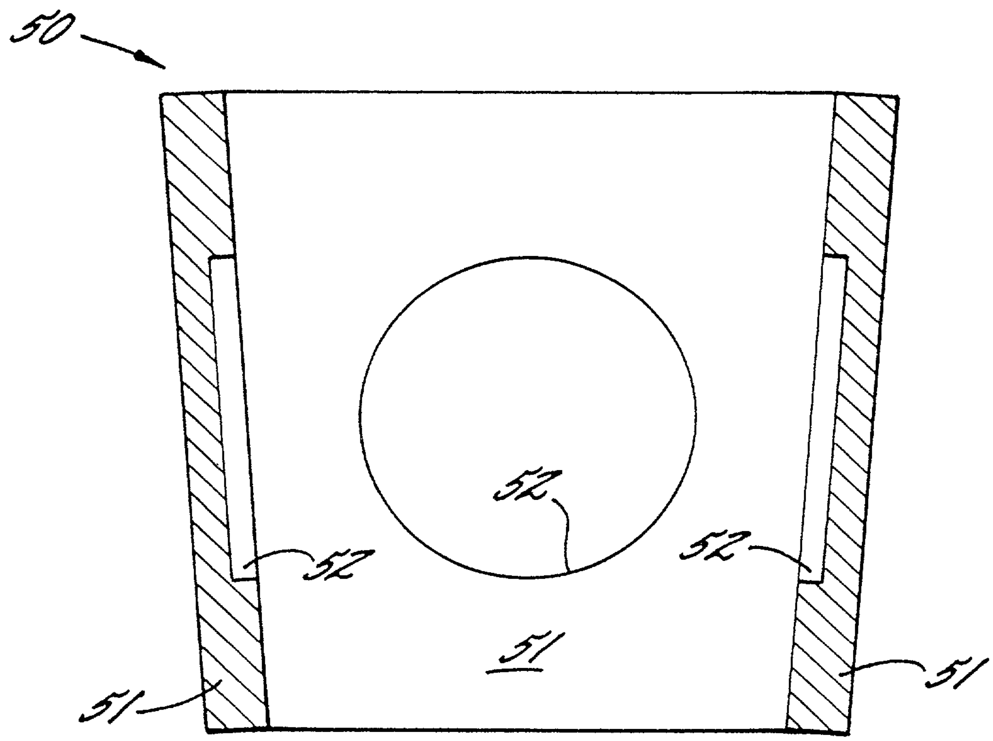

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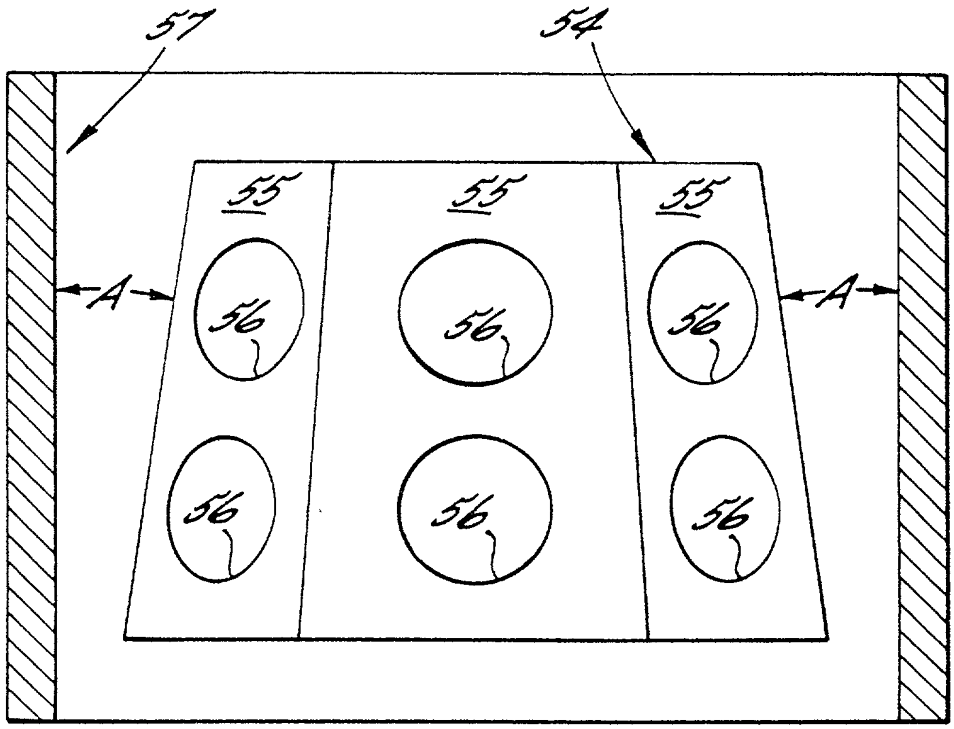

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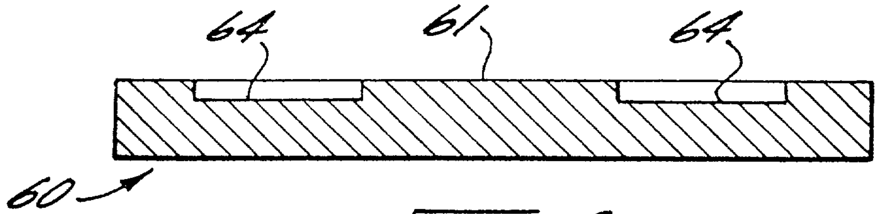

Fig. 8.

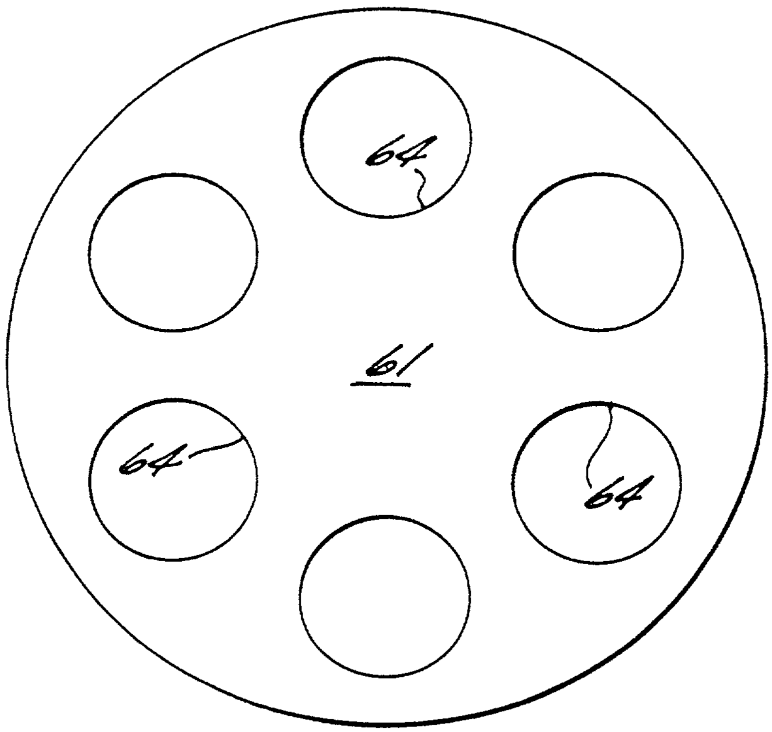

Fig. 9.

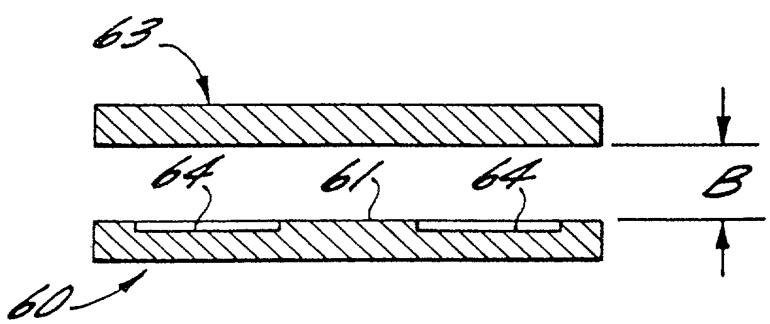

Fig. 10.

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Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION

☐ Declaration Submitted with Initial Filing OR ☒ Declaration Submitted after Initial Filing

Attorney Docket Number	5000.89
First Named Inventor	Kong
COMPLETE IF KNOWN	
Application Number	08/823,365
Filing Date	March 24, 1997
Group Art Unit	1109
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled :

SUSCEPTOR DESIGNS FOR SILICON CARBIDE THIN FILMS

(Title of the Invention)

the specification of which

☐ is attached hereto

OR

☒ was filed on (MM/DD/YYYY) 03/24/1997 as United States Application Number or PCT International Application Number 08/823,365 and was amended on (MM/DD/YYYY) ______ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37 Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119 (a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or §365 (a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under Title 35, United States Code § 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	
		☐ Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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DECLARATION — Utility or Design Patent Application

I hereby claim the benefit under Title 35, United States Code §120 of any United States application(s), or §365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application Number	PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number *(if applicable)*

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: ☐ Customer Number ______ → *Place Customer Number Bar Code Label here*
OR
☒ Registered practitioner(s) name/registration number listed below

Name	Registration Number	Name	Registration Number
PHILIP SUMMA	31,573		

☐ Additional registered practitioner(s) named on supplemental Registered Practitioner Information sheet PTO/SB/02C attached hereto.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

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☒ Additional inventors are being named on the 1 supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

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DECLARATION

ADDITIONAL INVENTOR(S)
Supplemental Sheet
Page 1 of 1

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Post Office Address							
City	Apex	State	NC	ZIP	27502	Country	US

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname

Inventor's Signature						Date	
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		ZIP		Country	

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